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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B22D 27/04, B22C 9/28

A1

(11) International Publication Number: WO 95/09710

(43) International Publication Date: 13 April 1995 (13.04.95)

(21) International Application Number: PCT/US94/11249

(22) International Filing Date: 4 October 1994 (04.10.94)

(30) Priority Data:
08/133,476 7 October 1993 (07.10.93) US

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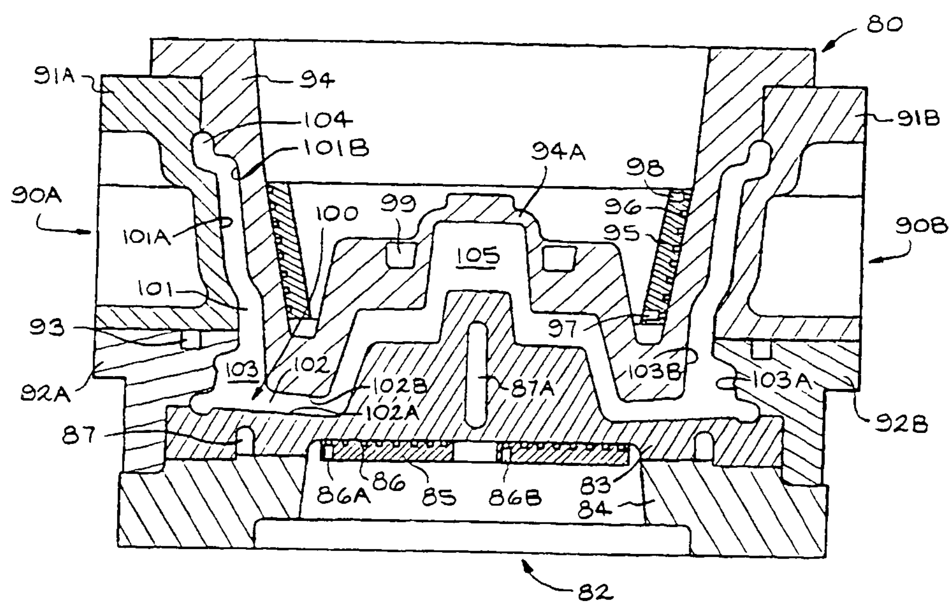
(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CN, CZ, DE, EE, ES, FI, GB, GE, HU, JP, KG, KP, KR, KZ, LK, LR, LT, LV, MD, MG, MN, NL, NO, NZ, PL, RO, RU, SE, SI, SK, TJ, TT, UA, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ).

Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD AND APPARATUS FOR CONTROLLED DIRECTIONAL SOLIDIFICATION OF A WHEEL CASTING



(57) Abstract

A method and apparatus for casting a metal wheel (50) having a wheel disk formed across a wheel rim (51). Forced cooling is applied to a wheel casting mold (80). The forced cooling controls the cooling of the molten metal in the mold cavity (101, 102, 103) such that solidification of the wheel casting occurs within the rim (51) and wheel disk (58) portions in a predetermined, controlled manner. Preferably, solidification begins at the junction of the wheel rim and disk and proceeds concurrently axially across the rim and radially across the wheel disk. This controlled directional solidification within the rim and wheel disk portions significantly reduces the amount of time required to cast a wheel casting and results in a lighter, stronger wheel.

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TITLE

METHOD AND APPARATUS FOR CONTROLLED DIRECTIONAL SOLIDIFICATION OF A WHEEL CASTING

BACKGROUND OF THE INVENTION

This invention relates in general to cast vehicle wheels and in particular to a method and an apparatus for casting such wheels.

Cast wheels formed from light weight metal alloys are replacing steel wheels on an increasing number of vehicles. Such cast wheels provide both a reduction in weight from steel wheels and an attractive appearance. Cast wheels are cast by pouring a molten metal, typically an alloy of a light weight metal, such as aluminum, magnesium or titanium, into a wheel mold assembly to form a wheel casting.

Referring to the drawings, there is shown in FIG. 1 a sectional view of a typical wheel casting, indicated generally at 10, formed in accordance with the prior art. For clarity, section lines have been omitted from FIG. 1. Additionally, in the following discussion of the wheel casting, "inner" refers to a portion of the wheel oriented towards a vehicle (not shown) when the wheel is mounted thereon while "outer" refers to a portion of the wheel oriented away from the vehicle.

The wheel casting 10 includes a relatively thin annular rim portion 11 which carries a vehicle tire (not shown). The rim portion 11 has a recessed center well 12 formed between inner and outer bead seats 13 and 14. An inner flange 15 is formed on the inner edge of the inner bead seat 13 and extends radially outward. An annular rim riser 16 extends axially upward in FIG. 1 from the inner flange 15. An outer flange 17 is formed on the outer edge of the outer bead seat 14 and extends radially outward. The flanges 15 and 17 function to retain a vehicle tire upon the finished wheel.

A wheel disk 18 extends across the outer end of the casting 10. The junction of the wheel disk 18 to the rim portion 11 forms a sidewall 14A which is accordingly thicker than either the wheel disk 18 or the rim portion 11. The wheel disk 18 typically includes a plurality of openings (not shown) formed therethrough which allow a flow of cooling air to the vehicle brakes while reducing the wheel weight. A wheel hub 19 is formed in the center of the wheel disk 18. The hub 19 includes a central aperture which receives an axle end (not shown) and a plurality of bolt holes (not shown) for attaching the finished wheel to a vehicle. A generally cylindrical hub riser 20 extends upward in FIG. 1 from the inner end of the wheel hub 19.

Once the wheel casting 10 has cooled sufficiently, it is removed from the mold and machined to final shape. The wheel also can be subjected to solution heat treatment and aging. The outer surface of the wheel disk is often highly polished and can include decorative painted portions.

The manner in which the molten metal forming the wheel casting 10 cools and the structure of the mold in which the wheel is cast affect the physical characteristics of the wheel. For the following discussion, portions of the wheel section shown in FIG. 1 are labeled with letters. The portion of the wheel 10 included in the inner flange 15 is labeled with the letter "A" and the narrowest section of the center well 12 is labeled with the letter "B". Similarly, the sidewall 14A is labeled with the letter "C" and the narrowest section of the wheel disk 18 is labeled with the letter "D". The wheel hub 19 is labeled with the letter "E".

The molten metal forming the wheel casting 10 solidifies first in the thinnest portions of the casting, since these portions cool the fastest. Thus, solidification of the molten metal typically begins in the shaded portions of the center well 12 and wheel disk 18 shown in FIG. 1 and labeled B and D. The solidification

then proceeds towards the thicker portions of the wheel casting 10 as illustrated with small direction arrows on FIG. 1. As shown in FIG. 1, the solidification proceeds in two axial directions simultaneously through the rim portion 11, from B inwardly towards A, and from B outwardly towards C. Similarly, the solidification of the wheel disk 18 proceeds in two radial directions simultaneously from D outwardly towards C and inwardly towards E. Finally, solidification begins at the outboard flange 17 and proceeds towards C.

The cooling rate and thereby the solidification of the molten metal can be further affected by the particular mold geometry to the extent that it is not possible to identify solidification directions.

As the molten metal solidifies, a crystalline structure consisting of individual metal grains is formed in the wheel casting 10. The individual grains vary in size within the casting 10. Generally, the portion of the casting 10 that solidifies first has a smaller grain size and the grain size increases proportionally with the length of time required for cooling. The average grain size for the prior art wheel casting 10 as a function of position within the casting 10 is graphically illustrated in FIG. 2 by the line 30. The letters shown along the horizontal axis in FIG. 2 correspond to the letter labels shown in FIG. 1 and indicate the relative position on the wheel casting 10. For the typical wheel casting 10 illustrated in FIG. 2, the grain sizes vary over a wide range, from 44 to 106 microns (um). The minimum grain size illustrated in FIG. 2 corresponds to the portions B and D of the wheel casting 10 which solidify first. The larger grain sizes indicated for portions A and E, which solidify last, result in an increased porosity in these portions of the wheel casting 10. Large grain size causes a low structural casting strength and the high porosity can allow escape of the pressurized air contained in a tire mounted upon the

finished wheel. The irregular shape of the line 30 indicates that solidification occurred in multiple directions in the rim portion 11 and the wheel disk 18.

The crystalline structure of the wheel casting 10 is related to the mold used to cast the wheel. Cast wheels are typically formed by gravity feeding or pressure injecting molten metal into a mold cavity formed in a multi-piece steel wheel mold assembly. A simplified sectional view of a prior art multi-piece mold assembly 40 for casting the wheel casting 10 is shown in FIG. 3. The individual pieces of the mold assembly 40 are typically formed from cast iron or high carbon steel. The mold assembly 40 includes a base member 41 which supports the other pieces of the mold assembly 40. Two or more retractable side members 42A and 42B are carried by the base member 41. A removable cup-shaped core member 43 having a cylindrical center portion 43A is disposed within the mold side members 42A and 42B.

The mold members 41, 42A, 42B and 43, upon assembly, define a main mold cavity 44 wherein the wheel casting 10 is cast. The main cavity 44 includes an annular rim cavity 45 for casting the wheel rim portion 11 and a disk cavity 46 for casting the wheel disk 18. An annular sidewall cavity 47 for casting the wheel sidewall 14A joins the rim cavity 45 to the disk cavity 46. The base member 41 defines the outer surface 46A of the disk cavity 46. Similarly, the side members 42A and 42B define outer surfaces 45A and 47A of the rim and sidewall cavities 45 and 47. The core member 43 defines inner surfaces 45B and 47B of the rim and sidewall cavities 45 and 47 and an inner surface 46B of the disk cavity 46. The side members 42A and 42B and the core member 43 further define an annular rim riser cavity 48 formed adjacent to the rim cavity 45. Similarly, a cylindrical hub riser cavity 49 is formed in the core member center portion 43A adjacent to the inner center of the disk cavity 46.

To cast a wheel casting 10, molten metal is fed by a conventional method, such as gravity or under pressure, into the main cavity 44 through a sprue (not shown). The molten metal flows into the disk, sidewall and rim cavities 46, 47 and 45, and then fills the rim and hub riser cavities 48 and 49. Molten metal flows from the riser cavities 48 and 49 into the main cavity 44 to fill any voids formed as the metal in the main cavity 44 cools and contracts.

To facilitate the flow of molten metal contained in the riser cavities 48 and 49 into the main cavity 44 as needed, the rim and disk cavities 45 and 46 are purposely made wide. The wide rim and disk cavities 45 and 46 join to form a wide sidewall cavity 47. Thus, the resulting wheel casting 10 has a relatively thick rim portion 11, sidewall 14A and wheel disk 18. The thick rim portion 11 and wheel disk 18 require a long cooling time for the molten metal forming them to solidify. Accordingly, the riser cavities 48 and 49 are made large to hold sufficient metal to assure that a portion of the metal within the risers remains molten until needed. However, as described above, the molten metal solidifies first in the shaded areas B and D in FIG. 1. This blocks the flow of molten metal from the rim and hub risers 48 and 49 from reaching the outer portions of the rim portion 11 and wheel disk 18 and the side wall 14A. Thus, the resulting shrinkage of the metal in these portions cannot be replaced with molten metal from the riser cavities 48 and 49. This unreplenished metal shrinkage can result in formation of voids in the sidewall 14A, the rim portion 11 and the wheel disk 18. Such voids weaken the finished wheel and potentially mar the wheel appearance.

The long cooling time necessitated by the wide mold cavities and thick castings results in formation of relatively large sized grains in the crystalline structure of the castings, as illustrated in FIG. 2. As described

above, large grain structure causes a low structural casting strength and high porosity. High porosity of the wheel rim 11 can allow escape of the pressurized air contained in the tire mounted upon the finished wheel. The thick rim portion 11 and wheel disk 18 compensate for this greater porosity of the casting 10. This avoids rejection of the finished wheel formed from the casting 10 due to potential air leakage therethrough. To provide sufficient wheel strength and maintain tire pressure, the thick rim portion and wheel disk are retained when the casting 10 is machined to final shape. However, this results in a relatively heavy finished wheel and requires more material to cast each wheel.

SUMMARY OF THE INVENTION

This invention relates to a method and an apparatus for controlling the cooling of the molten metal forming the a wheel casting such that solidification occurs in a predetermined manner within the rim and wheel disk portions thereof. The wheel casting so formed includes an annular rim portion joined to a wheel disk by an annular sidewall. The wheel disk is formed across the outer end of the rim portion and includes a central hub.

The method for controlling the cooling of molten metal within portions of the wheel casting includes providing a wheel mold having a mold cavity shaped to form the wheel casting. Molten metal is introduced into the mold cavity. The molten metal within the mold is caused to solidify first in the region of wheel sidewall. Solidification of the molten metal in the rim portion of the wheel then proceeds in an axial direction from the sidewall towards the end of the rim portion opposite from the wheel disk. Solidification of the molten metal in the disk portion of the wheel can occur concurrently with the solidification of the rim portion of the wheel and proceeds in a radial direction from the sidewall towards the center of the disk.

After sufficient cooling, the casting is removed from the mold cavity.

The apparatus for controlling the cooling of molten metal includes a wheel mold having forced cooling means for controlling the initial solidification of the molten metal and the subsequent direction thereof. The cooling means includes a circumferential cooling passageway formed in the sides of the wheel mold in the vicinity of the wheel sidewall. A cooling medium is circulated through the passageway to rapidly cool and solidify the molten metal adjacent thereto causing initial solidification of the casting in the vicinity of the sidewall. Additional cooling passageways are formed within the wheel mold and in cooling blocks attached to surfaces of the wheel mold. These passageways are used to apply additional forced cooling to establish temperature gradients across the casting rim portion and wheel disk. The forced cooling can be sequentially applied to further control the direction of solidification.

The method and apparatus of the invention produce an improved wheel casing having a finer grain size, increased strength and reduced porosity than a comparable prior art wheel casting. The increased strength and reduced porosity allow production of a thinner rim portion and wheel disk, reducing wheel weight and the amount of material required to form a wheel. Finer grain size also generally corresponds to faster cooling. Faster cooling allows a higher wheel production rate for a fixed number of wheel molds.

Other advantages of this invention will become apparent to those skilled in the art from the following detailed description of the preferred embodiment, when read in light of the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional view of a wheel casting formed in accordance with the prior art.

FIG. 2 is a graph showing the average size of metal grains in the wheel casting shown in FIG. 1.

FIG. 3 is a sectional view of a prior art mold assembly used to cast the wheel casting shown in FIG. 1.

FIG. 4 is a sectional view of a wheel casting formed in accordance with the present invention.

FIG. 5 is a graph comparing the average size of grains in the wheel casting shown in FIG. 4 to the average size of grains in the wheel casting shown in FIG. 1.

FIG. 6 is a sectional view of an improved mold assembly used to cast the wheel casting shown in FIG. 4.

FIG. 7 is a sectional view of an improved mold assembly in accordance with the present invention which is used to cast a low offset wheel.

FIG. 8 is a sectional view of a cast full face modular wheel having a cast wheel disk attached to a separately formed partial wheel rim.

FIG. 9 is a sectional view of an improved mold assembly in accordance with the present invention which is used to cast the wheel disk shown in FIG. 8.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring again to the drawings, there is shown in FIG. 4 a sectional view of an improved wheel casting, indicated generally at 50, formed in accordance with the present invention. For clarity, section lines have been omitted from FIG. 4. As in the above, in the following discussion of the wheel casting, "inner" refers to a portion of the wheel oriented towards a vehicle (not shown) when the wheel is mounted thereon while "outer" refers to a portion of the wheel oriented away from the vehicle.

While FIG. 4 shows a one piece wheel casting 50, the invention can be practiced upon only a cast component of a multi-piece wheel such as, for example, a center spider

portion (not shown), which is then secured to a separately formed rim (not shown) in a know manner to form a finished wheel. As will be described below, the cast component can also be the full front face of a wheel which is subsequently secured to a formed partial wheel rim. Thus, as used in this description and the following claims, the term "wheel casting" includes not only a one piece wheel casting, but also a component casting of a multi-piece wheel.

The improved casting 50 has the same general shape as the prior art casting 10 described above and is intended for use as a replacement therefor. Similar to the prior art casting 10 shown in FIG. 1, the improved casting 50 includes an annular rim portion 51. The rim portion 51 has a recessed center well 52 formed between inner and outer bead seats 53 and 54. An inner flange 55 is formed on the inner edge of the inner bead seat 53 and extends radially outward. An annular rim riser 56 extends axially upward in FIG. 4 from the inner flange 55. An outer flange 57 is formed on the outer edge of the outer bead seat 54 and extends radially outward. A wheel disk 58 extends across the outer end of the casting 50. The junction of the wheel disk 58 to the outer end of the rim portion 51 forms a thick sidewall 54A. A hub 59 is formed in the center of the wheel disk 58. A generally cylindrical hub riser 60 is provided on the inner end of the wheel hub 59.

As will be explained below, the rim portion 51 and the wheel disk 58 of the improved casting 50 are thinner than the corresponding portions of the prior art casting 10. Furthermore, the risers 56 and 60 are smaller than the prior art wheel risers 16 and 20.

For the following discussion, portions of the wheel section shown in FIG. 4 are also labeled with letters. Thus, the portion of the wheel 50 included in the inner flange 55 is labeled with the letter "A'" and the narrowest section of the center well portion 52 is labeled with the

letter "B'". Similarly, the sidewall 54A is labeled with the letter "C'" and the narrowest section of the wheel disk 58 is labeled with the letter "D'". The wheel hub 59 is labeled with the letter "E'".

As will also be explained below, the direction of solidification of the molten metal forming the improved casting 50 is carefully controlled. Directional arrows in FIG. 4 indicate the direction for solidification of the molten metal forming the casting 50. The solidification begins in the shaded area in FIG. 4 which includes the outer flange 57, a portion of the sidewall 54A labeled C' and a portion of the center well 52 labeled B' adjacent to the sidewall 54A. The solidification then concurrently proceeds in two directions. One direction is axially across the wheel rim portion 51 towards A'. The second direction is radially inwardly across the wheel disk 58 towards E'. Thus, solidification of the improved casting 50 is controlled to proceed in particular direction within the rim and wheel disk portions 51 and 58 of the wheel casting 50.

The improved wheel casting 50 is cooled more quickly than the prior art wheel casting 10. This causes the improved wheel casting 50 to have a finer grain structure than the prior art casting 10. This is illustrated in FIG. 5, where the grain size as a function of position within the improved casting 50 is shown with the solid line 70. For comparison, the average grain sizes for the prior art casting 10 shown in FIG. 2 are included in FIG. 5 with a dashed line 71. The improved casting 50 exhibits a finer grain structure than the prior art casting 10 throughout. For the typical wheel casting 50 illustrated in FIG. 4, the grain sizes vary over a narrow range from 28 um to 65 um. Compared to the prior art wheel casing 10, the average casting grain size in the improved casting 50 has been reduced by the present invention by approximately 38 percent. Furthermore, the grain size is relatively uniform

for a large portion of the casting 50 extending from B' to D'.

A simplified sectional view of an improved multi-piece mold assembly 80 for casting the improved wheel casting 50 is shown in FIG. 6. As in the prior art mold assembly 40, the improved mold assembly 80 is formed from cast iron or high carbon steel. Similar to the prior art mold assembly 40, the improved mold assembly 80 includes a base member 82 which supports the other pieces of the mold assembly 80. The base member 82 has a generally disk-shaped upper portion 83 mounted upon a ring shaped lower portion 84. A disk-shaped base cooling block 85 formed of a metal having a high heat conductivity is attached to the bottom surface of the base member upper portion 83. The base cooling block 85 includes a spiral passageway 86 formed therein for conducting a cooling medium, as will be described below. The passageway 86 includes an inlet port 86A formed near the perimeter of the cooling block 85 and an outlet port 86B formed near the center of the block 85. The base upper portion 83 further includes a circumferential ring-shaped cooling passageway 87 formed therein adjacent to the base lower portion 84. The base upper portion 83 also includes an axial cooling passageway 87A formed therein extending into the center of the base member upper portion 83.

Two or more retractable side members 90A and 90B are carried by the base member 82. Similar to the base member 82, the side members 90A and 90B include upper portions 91A and 91B and lower portions 92A and 92B. A ring-shaped passageway 93 is formed in the lower side portions 92A and 92B adjacent to the upper side portions 91A and 91B. As will be described below, the passageway 93 is also located adjacent to the portion of the mold 80 which forms the casting sidewall 54A. The passageway 93 carries a cooling medium, as will be described below.

A removable cup-shaped core member 94 having a cylindrical center portion 94A is disposed within the side

members 90A and 90B. An inner cooling block 95 having an inverted frustum shape is attached to the lower portion of the inner surface of the core member 94. The inner cooling block 95 is formed from a metal having a high heat conductivity and includes a passageway 96 formed therein for conducting a cooling medium. The passageway 96 can be formed in a spiral shape from the bottom to the top of the inner cooling block 95. An inlet port 97 formed near the bottom of the cooling block 95 receives a cooling medium and an outlet port 98 formed near the top of the cooling block 95 discharges the cooling medium.

As an alternate, the cooling passageway 96 can be formed as a plurality of parallel vertical passageways (not shown). The lower ends of the vertical passageways communicate with a ring-shaped inlet header (not shown) formed in the bottom of the cooling block 95. Similarly, the upper ends of the vertical passageways communicate with a ring-shaped outlet header (not shown) formed in the top of the cooling block 95. The use of the inner cooling block 95 will be described below.

The core member 94 further has a ring-shaped central cooling passageway 99 formed within the cylindrical center portion 94a.

The assembled mold members 82, 90A, 90B and 94 define a main mold cavity 100. Similar to the prior art mold 40, the main cavity 100 includes an annular rim cavity 101 for casting the wheel rim portion 51 and a disk cavity 102 for casting the wheel disk 58. An annular sidewall cavity 103 for casting the wheel sidewall 54A joins the rim cavity 101 to the disk cavity 102. As will be explained below, the rim, sidewall and disk cavities 101, 103 and 102 are narrower than the corresponding cavities in the prior art mold assembly 40. The base member 82 defines an outer surface 102A of the disk cavity 102. The side members 90A and 90B define outer surfaces 101A and 103A of the rim and sidewall cavities 101 and 103. The core member 94 defines

inner surfaces 101B and 103B of the rim and sidewall cavities 101 and 103 and an inner surface 102B of the disk cavity 102. The upper side members 91A and 91B and the core member 94 further define an annular rim riser cavity 104 formed adjacent to the rim cavity 101. A cylindrical hub riser cavity 105 is formed in the cylindrical portion 94A of the core member 94 adjacent to the inner center of the disk cavity 102. As will be explained below, the improved mold assembly 80 has smaller rim riser and hub riser cavities 104 and 105 than the prior art mold assembly 40.

The operation of the improved mold assembly 80 to cast an improved wheel casting 50 will now be described. Molten metal is introduced into the main cavity 100 by conventional means, such as gravity feed or low pressure injection through a sprue (not shown). The molten metal fills the main cavity 100 and the riser cavities 104 and 105.

Forced cooling is applied to the mold assembly 80 by circulating a cooling medium through the side mold cooling passageway 93. Typical cooling mediums include air, a water and air mist and cooling water. However, other cooling mediums can be used. The above is applicable when a cooling medium is referenced in the following discussion.

The forced cooling rapidly cools the molten metal in the main mold cavity 100 adjacent to the passageway 93, which is in the vicinity of the outer bead seat 54 and sidewall 54A of the casting 50. This causes solidification of the molten metal forming the wheel casting 50 to begin in the vicinity of the sidewall 54A as shown by the shaded areas shown in FIG. 4. The solidification of the molten metal then continues concurrently in two directions, as illustrated with small direction arrows on FIG. 4. The solidification proceeds axially across the rim cavity 101 towards the inner flange 55. At the same time,

solidification proceeds radially inwardly across the wheel disk cavity 102 towards the center of the wheel disk 58.

Additional forced cooling is applied to the rim cavity 101 by circulating a cooling medium through the cooling passageway 96 in the core inner cooling block 95. The cooling medium is injected into the inlet port 97 located at the bottom of the cooling block 95 and discharged from the outlet port 98 at the top of the cooling block 95. As the cooling medium passes from the inlet port 97 to the outlet port 98, the cooling medium temperature increases as heat is transferred from the molten metal. Thus, greater cooling occurs at the base of the side of the core member 94 with the cooling effect lessening in the direction of the top of the core member 94. This creates a temperature gradient axially across the inner surface 101B of the rim cavity 101, further controlling the solidification to occur thereacross in a particular direction. This additional forced cooling can be initiated at the same time as the forced cooling in the vicinity of the sidewall 54A or delayed in time relative thereto.

Forced cooling is applied to the base upper portion 83 by circulating a cooling medium through the mold base cooling passageways 87 and 87A and the spiral cooling passageway 86 in the mold base cooling block 85. As described above, the cooling medium is injected into the spiral passageway 86 near the perimeter of the cooling block 85 and removed from the passageway 86 near the center of the block 85. As the cooling medium passes through the spiral passageway 86, the cooling medium temperature increases as heat is transferred from the molten metal. Thus, greater cooling occurs at the perimeter of the cooling block 85 than at the center thereof. This creates a radial temperature gradient across the outer surface 102A of the disk cavity 102 that further controls the solidification of the molten metal forming the wheel disk 58 to occur in a particular direction.

The cooling medium can be applied to all the base cooling passageways 87, 86 and 87A simultaneously or sequentially. As with the core member 94, the forced cooling of the base upper portion 83 can be initiated at the same time as the forced cooling in the vicinity of the sidewall 54A or delayed relative thereto.

Cooling of the casting 50 is completed by circulating cooling medium through the hub riser cooling passageway 99 to solidify the metal in the hub riser cavity 105.

In the preferred embodiment, sequential application of the forced cooling has been successfully used. Such sequential application includes initiating the cooling on the exterior of the side members 90A and 90B, then, after a delay, cooling the inner surface of the core member 94. Following a further delay, cooling is applied to the base upper portion 83. Finally, cooling is applied to the cylindrical portion 94A of the core member 94.

As the rim portion 51 of the casting 50 solidifies in an axial direction from the sidewall 54A towards the inner flange 53, molten metal is withdrawn from the rim riser cavity 104 to compensate for metal contraction. However, with the improved mold assembly 80, the molten metal is not blocked by solidified metal, as described above for the prior art mold assembly 40. Similarly, as the wheel disk 58 solidifies in a radial direction from the sidewall 54A towards the hub 59, molten metal is withdrawn from the hub riser cavity 105 to compensate for metal contraction. Thus, the potential of forming voids in the portion indicated by C' is greatly reduced in the improved wheel casting 50.

As mentioned above, the rapid cooling significantly reduces the grain size in the crystalline structure of the casting 50. The finer grain size results in a stronger wheel casting 50 having less porosity than the prior art casting 10. Accordingly, the rim portion 51, the sidewall portion 54A and the wheel disk 58 of the improved casting

50 are cast thinner than the corresponding portions of the prior art casting 40. The resulting thinner wheel is lighter in weight than the prior art wheel and requires less material.

Accordingly, the rim, sidewall and disk cavities 101, 103 and 102 of the improved mold 80 are narrower than the corresponding cavities in the prior art mold 40. With narrower cavities, the molten metal in the improved mold 80 cools faster than in the prior art mold 40. Thus, the length of time during which the metal within the rim and hub riser cavities 104 and 105 must be maintained in a molten state is reduced. This allows reduction of the size of the rim and hub riser cavities 104 and 105 from the size of the corresponding riser cavities used in the prior art mold 40.

The reduced cooling time required for solidification of the metal within the improved mold 80 described above has substantially reduced the time required to cast a wheel. Typically, five to seven minutes are required to cast a wheel according to the prior art. With the present invention, casting time for an equivalent wheel is reduced to three to four minutes per wheel. Thus, the present invention significantly increases the rate of wheel production for a fixed number of molds. Additional savings in production time are achieved because less machining of the wheel casting 50 is required to finish the wheel.

Because of the lower porosity of the improved wheel casting 50, the thinner rim portion 51 does not leak air from the tire mounted thereupon.

It is to be appreciated that the invention also can be practiced on low offset wheels (not shown) in which the wheel disk is axially recessed within the wheel rim. A simplified sectional view of an improved multi-piece mold assembly 110 for casting a low offset wheel is shown in FIG. 7. The improved mold assembly 110 includes a base member 111 which supports the other pieces of the mold

assembly 110. The base member 111 has a generally disk-shaped upper portion 112 mounted upon a ring shaped lower portion 113. A disk-shaped base cooling block 114 formed of a metal having a high heat conductivity is attached to the bottom surface of the base member upper portion 112. The base cooling block 114 includes a spiral passageway 115 formed therein for conducting a cooling medium. The passageway 115 includes an inlet port 116 formed near the perimeter of the cooling block 114 and an outlet port 117 formed near the center of the block 114. The base upper portion 112 further includes a circumferential ring-shaped internal cooling passageway 118 formed therein adjacent to the base lower portion 113. The base upper portion 112 also includes an axial internal cooling passageway 119 formed therein extending into the center of the base member upper portion 112.

Two or more retractable side members 120 and 121 are carried by the base member 111. Similar to the base member 111, the side members 120 and 121 include upper portions 122 and 123 and lower portions 124 and 125. A ring-shaped passageway 126 is formed in the lower side portions 124 and 125 adjacent to the upper side portions 122 and 123. As will be described below, the passageway 126 is located adjacent to the portion of the mold 110 which forms the juncture of the wheel disk and wheel rim. The passageway 126 carries a cooling medium, as was described above.

A removable cup-shaped core member 130 having a cylindrical center portion 131 is disposed within the side members 120 and 121. An inner cooling block 132 having an inverted frustum shape is attached to the lower portion of the inner surface of the core member 130. The inner cooling block 132 is formed from a metal having a high heat conductivity and includes a passageway 133 formed therein for conducting a cooling medium. The passageway 133 can be formed in a spiral shape from the bottom to the top of the inner cooling block 132. An inlet port 134 formed near the

bottom of the cooling block 132 receives a cooling medium and an outlet port 135 formed near the top of the cooling block 132 discharges the cooling medium. Alternately, the cooling passageway 133 can be formed as a plurality of parallel vertical passageways (not shown). The core member 130 further has a ring-shaped internal cooling passageway 136 formed within the cylindrical center portion 131.

The assembled mold members 111, 120, 121 and 130 define a mold cavity 140 which includes an annular rim cavity 141 having inner and outer flange cavities 142 and 143 and a disk cavity 144 having a central hub cavity 145. The disk cavity 144 is axially recessed relative to the outer end of the rim cavity 141 to provide the desired amount of offset of the wheel disk within the wheel rim. Similar to the improved mold assembly 80 show in FIG. 6, a large disk edge cavity 146 is formed where the disk cavity 144 joins the rim cavity 141. Accordingly, the circular side mold cooling passageway 126 is located adjacent to the disk edge cavity 146.

To form a wheel casting with the improved mold 110, molten metal is introduced into the mold cavity 140. Forced cooling is applied to the mold assembly 110 by circulating a cooling medium through the side cooling passageway 126. This forced cooling rapidly cools the molten metal in the disk edge cavity 146 adjacent to the passageway 126, causing solidification of the molten metal forming the wheel casting to begin at the juncture of the wheel disk and the wheel rim. The solidification of the molten metal then continues concurrently in three directions. The solidification proceeds axially upward in FIG. 7 across the rim cavity 141 from the disk edge cavity 146 towards the inner flange cavity 142. At the same time, solidification proceeds radially inwardly across the wheel disk cavity 144 from the disk edge cavity 146 towards the hub cavity 145. Finally, the solidification proceeds axially downward in FIG. 7 across the rim cavity 141 from

the disk edge cavity 146 towards the outer flange cavity 143.

As described above, additional forced cooling can be applied to the mold assembly 110 by circulating a cooling medium through the base member cooling block 114 and internal passageways 118 and 119. Furthermore, cooling medium can be circulated through the core member cooling block 132 and internal cooling passageway 136.

As explained above, the present invention is also applicable to a multi-piece wheel. One type of multi-piece wheel is a full face modular wheel 150 illustrated in a sectional view in Fig. 8 as having a circular cast wheel disk 151 attached to a conventionally formed partial wheel rim 152.

A simplified sectional view of an improved multi-piece mold assembly 160 for casting the wheel disk 151 is shown in FIG. 7. The improved mold assembly 160 includes a base member 161 which supports the other pieces of the mold assembly 160. The base member 161 has a generally disk-shaped upper portion 162 mounted upon a ring shaped lower portion 163. Similar to the molds described above, a disk-shaped base cooling block 164 formed of a metal having a high heat conductivity is attached to the bottom surface of the base member upper portion 162. The base upper portion 162 further includes a circumferential ring-shaped internal cooling passageway 168 formed therein adjacent to the base lower portion 163. The base upper portion 162 also includes an axial internal cooling passageway 169 formed therein extending into the center of the base member upper portion 162.

Two or more retractable side members 170 and 171 are carried by the base member 161. A ring-shaped passageway 172 which carries a cooling medium is formed in the upper portion of the side portions 170 and 171. A removable cup-shaped core member 180 having a cylindrical center portion 181 is disposed within the side members 170 and

171. The core member 180 includes a ring-shaped internal cooling passageway 182 formed within the cylindrical center portion 181.

The assembled mold members 161, 170, 171 and 180 define a mold cavity 190 for casting the wheel disk 151. To cast a wheel disk 151 with the improved mold 160, molten metal is introduced into the mold cavity 190. Forced cooling is applied to the mold assembly 160 by circulating a cooling medium through the side cooling passageway 172. As described above, the forced cooling rapidly cools the molten metal in the mold cavity 190 adjacent to the passageway 172. This causes solidification of the molten metal forming the wheel casting to begin at the outer circumference of the wheel disk. The solidification of the molten metal then continues radially inwardly across the wheel disk cavity 190 towards the hub.

As described above, additional forced cooling can be applied to the mold assembly 110 by circulating a cooling medium through the base member cooling block 164 and internal passageways 168 and 169. Furthermore, cooling medium can be circulated through the core member internal cooling passageway 182.

In accordance with the provisions of the patent statues, the principle and mode of operation of this invention have been explained and illustrated in its preferred embodiment. However, it must be understood that this invention may be practiced otherwise than as specifically explained and illustrated without departing from its spirit or scope. For example, controlled solidification of the rim and disk portions 51 and 58 of the casting 50 can be accomplished by circulating a cooling medium only through the side mold cooling passageway 93. Accordingly, various combinations for applying cooling to the mold 80 and casting 50 are possible. Additionally,

while discrete cooling blocks 85 and 95 have been illustrated, the cooling passages 86 and 96 formed therein can also be formed within the mold assembly members 82 and 94.

What is claimed is:

1. A method for casting a vehicle wheel comprising the steps:

(a) providing a mold for a wheel, the mold having a cavity for casting a vehicle wheel;

(b) introducing a molten metal into the mold cavity;

(c) causing the molten metal within the mold to solidify first in a particular portion of the mold cavity;

(d) subsequent to step (c), controlling the solidification of the molten metal in the remainder of the mold cavity to cause the solidification thereof to proceed in a predetermined manner; and

(e) subsequent to sufficient cooling of the entire wheel casting, removing the casting from the mold cavity.

2. The method according to claim 1 wherein the mold cavity includes a circular disk cavity extending across an annular rim cavity with the juncture of the disk and rim cavities defining a sidewall cavity, and further wherein step (c) includes causing the molten metal to solidify first in the sidewall cavity.

3. The method according to claim 2 wherein step (d) includes controlling the solidification of the molten metal within the rim cavity to cause the solidification thereof to proceed in an axial direction across the rim cavity from the region of the sidewall cavity towards an axial end of the rim cavity.

4. The method according to claim 2 wherein step (d) includes controlling the solidification of the molten metal within the disk cavity to cause the solidification thereof to proceed in an inward radial direction.

5. The method according to claim 1 wherein step (c) includes applying forced cooling to the wheel mold.

6. The method according to claim 5 wherein step (a) includes providing a wheel mold having a side member defining the outside surfaces of the rim and sidewall cavities, the mold side member having a cooling passageway formed therein adjacent to the sidewall cavity and further wherein step (c) includes circulating a cooling medium through the cooling passageway.

7. The method according to claim 6 wherein the mold side member cooling passageway extends circumferentially about the mold side member.

8. The method according to claim 6 wherein step (a) further includes providing a wheel mold having a core member for forming the inside surface of the rim cavity, the core member including cooling means for establishing a temperature gradient axially across the rim portion and further wherein step (c) includes circulating a cooling medium through the core member cooling means.

9. The method according to claim 6 wherein step (a) further includes providing a wheel mold having a base member for forming the outer surface of the disk cavity, the base member including cooling means for establishing a temperature gradient radially across the disk cavity and further wherein step (c) includes circulating a cooling medium through the base member cooling means.

10. An apparatus for casting a one piece metal vehicle wheel comprising:

a wheel mold including an annular rim cavity shaped to form a wheel rim therein, a generally disk shaped cavity shaped to form a wheel disk therein, and an annular sidewall cavity shaped to form a wheel sidewall therein, said sidewall cavity joining said rim cavity to said disk cavity;

means for initially cooling a first portion of said wheel mold, said first portion being in the vicinity of said sidewall cavity; and

means for establishing a temperature gradient across a second portion of said mold subsequent to actuation of said means for cooling.

11. The apparatus according to claim 10 wherein said mold includes a side member for forming an outside surface of said sidewall cavity and further wherein said means for cooling includes a passageway for circulating a cooling medium formed in said mold side member in the vicinity of said sidewall cavity.

12. The apparatus according to claim 11 wherein said passageway extends circumferentially within said mold side member.

13. The apparatus according to claim 10 wherein said means for cooling is actuated before said means for establishing a temperature gradient.

14. The apparatus according to claim 10 wherein said mold includes a core member for forming an inside surface of said rim cavity and further wherein said means for establishing a temperature gradient includes a passageway for circulating a cooling medium formed within said core member, said passageway extending along an axial direction from a first axial end of said rim cavity adjacent to said sidewall cavity to a second axial end of said rim cavity opposite from said sidewall cavity, said passageway adapted to receive a cooling medium adjacent to said first axial end and to discharge said cooling medium adjacent to said second axial end.

15. The apparatus according to claim 10 wherein said mold includes a base member for forming the outer surface of the wheel disk cavity and further wherein said means for establishing a temperature gradient includes a passageway for circulating a cooling medium formed within said base member, said passageway extending along a radial direction from a first portion of said disk cavity adjacent to said sidewall cavity to a second portion of said disk cavity adjacent to said hub portion, said passageway adapted to receive said cooling medium adjacent to said sidewall cavity and to discharge said cooling medium adjacent to said hub portion.

16. An apparatus for casting a metal vehicle wheel comprising:

a wheel mold including a cavity shaped to form a vehicle wheel therein;

means for introducing molten metal into said cavity; and

means for controlling solidification of molten metal within said cavity in a predetermined manner.

17. The apparatus according to claim 16 wherein said means for controlling solidification includes means for initially solidifying molten metal in a particular portion of said cavity.

18. The apparatus according to claim 17 wherein said means for initially solidifying includes means for supplemental cooling of a portion of said mold.

19. The apparatus according to claim 16 wherein said means for controlling solidification includes means for establishing a temperature gradient across a portion of said mold whereby said molten metal solidifies in a predetermined direction.

20. The apparatus according to claim 19 wherein said means for establishing a temperature gradient includes means for supplemental cooling of a portion of said mold.

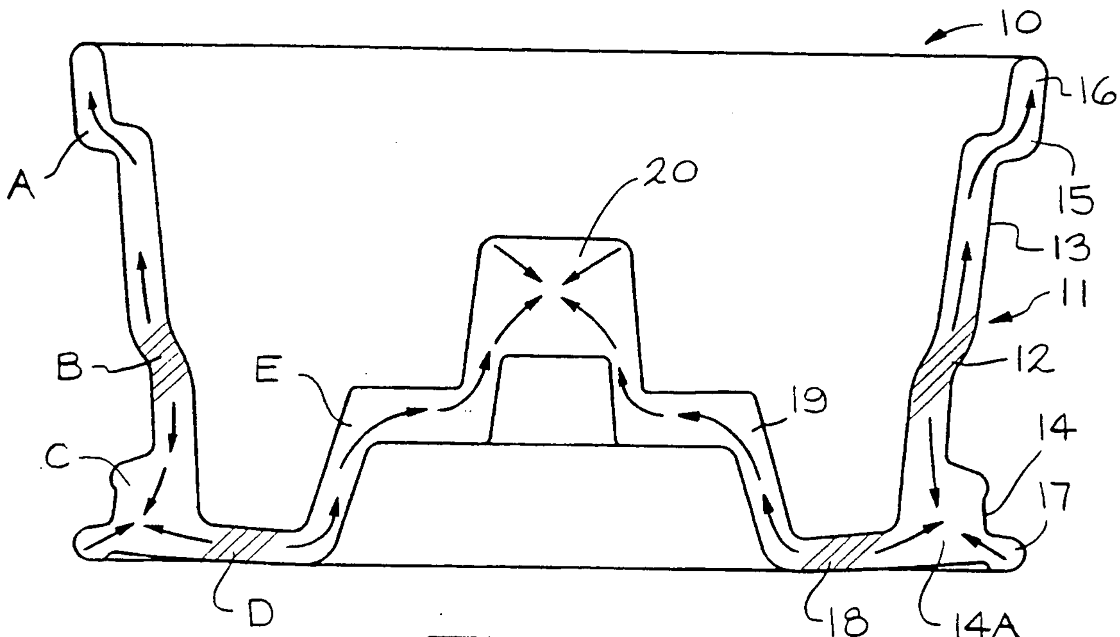

FIG. 1
(PRIOR ART)

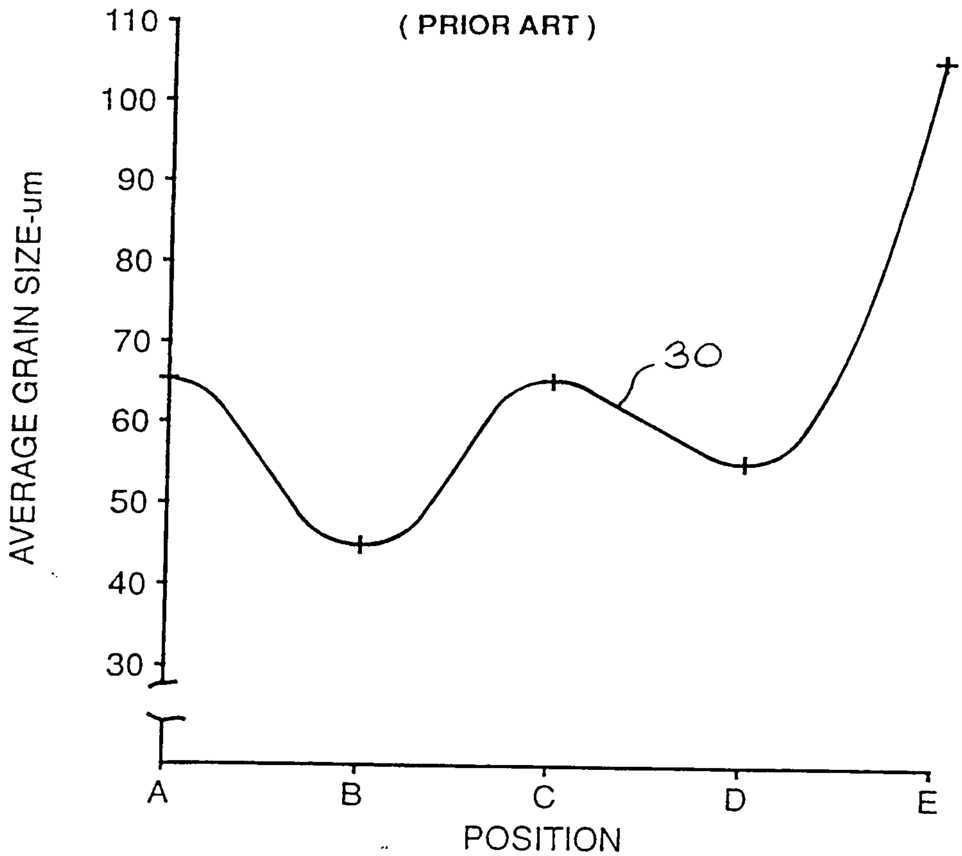

FIG. 2
(PRIOR ART)

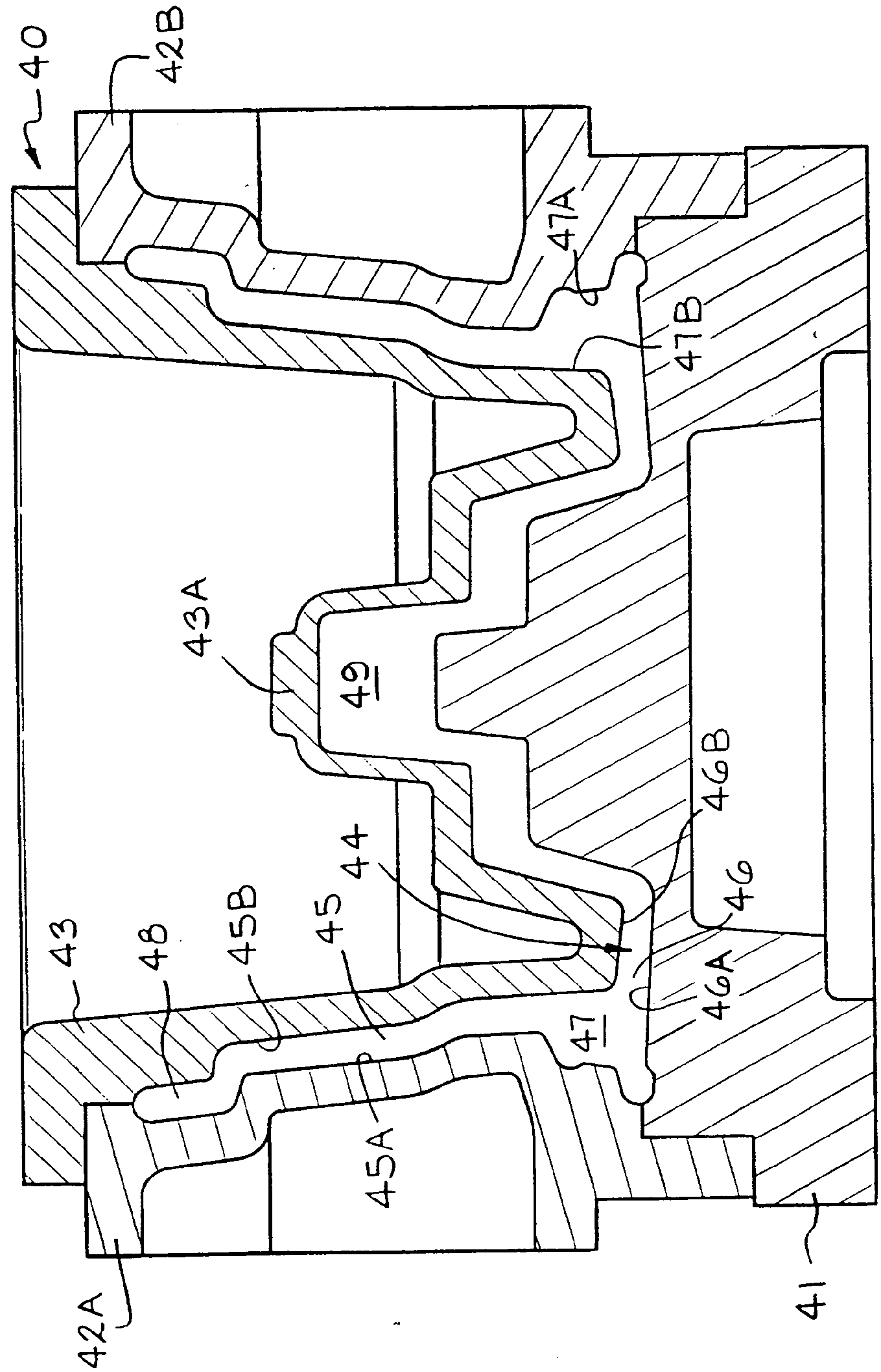

FIG. 3
(PRIOR ART)

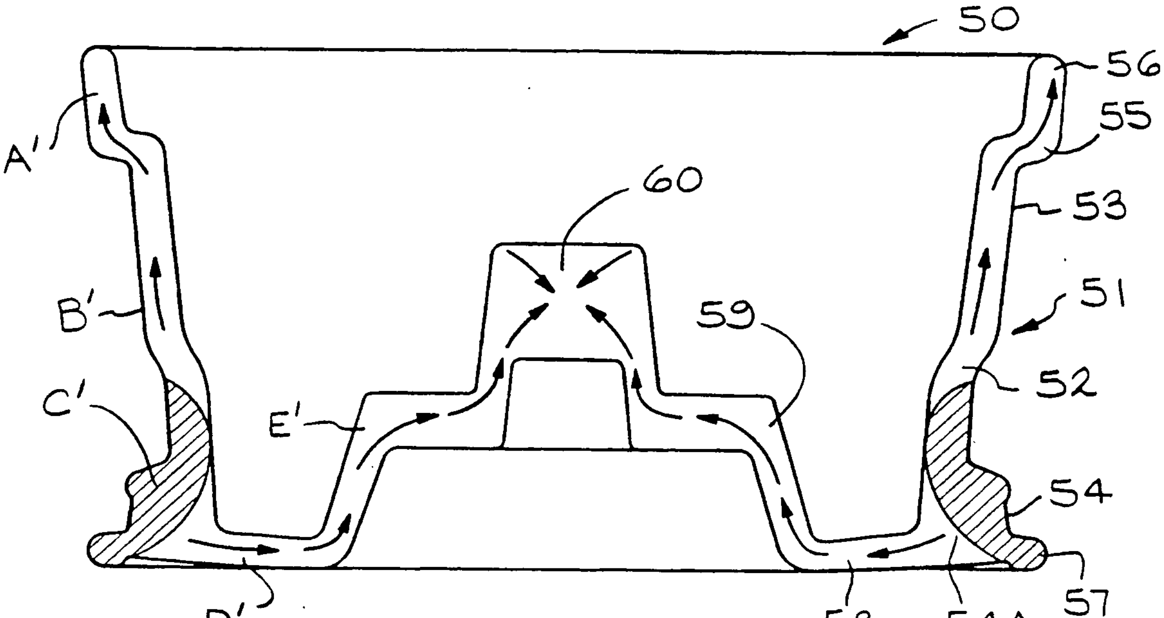

FIG. 4

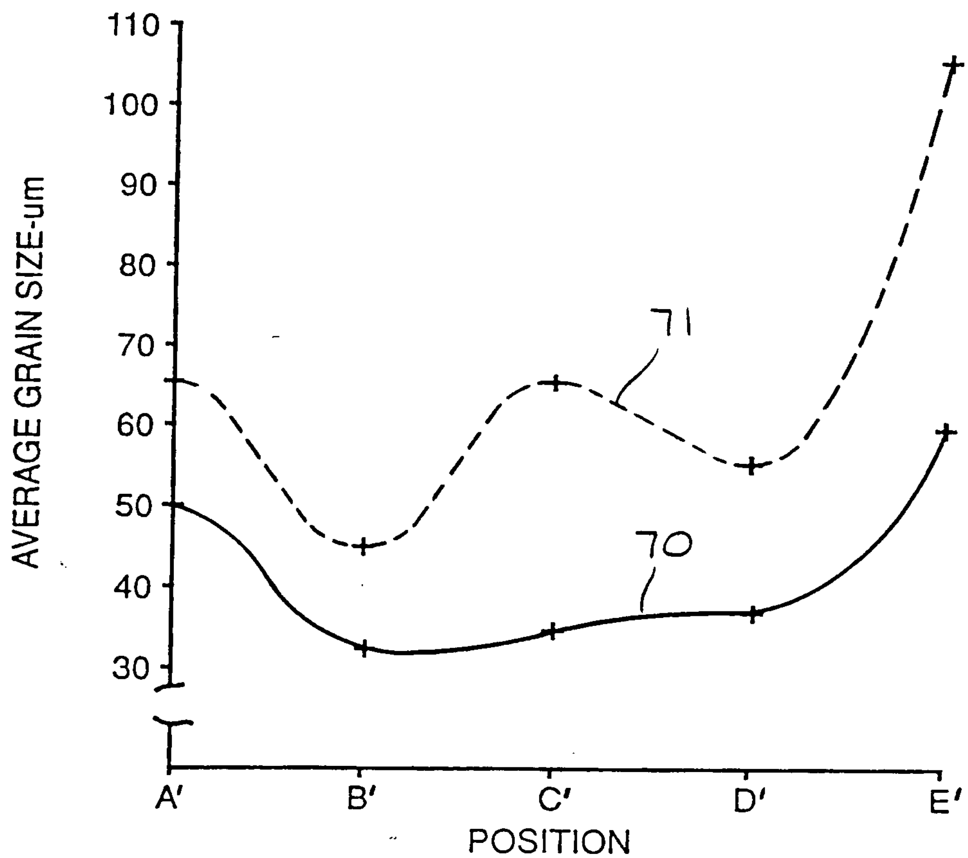

FIG. 5

SUBSTITUTE SHEET (RULE 26)

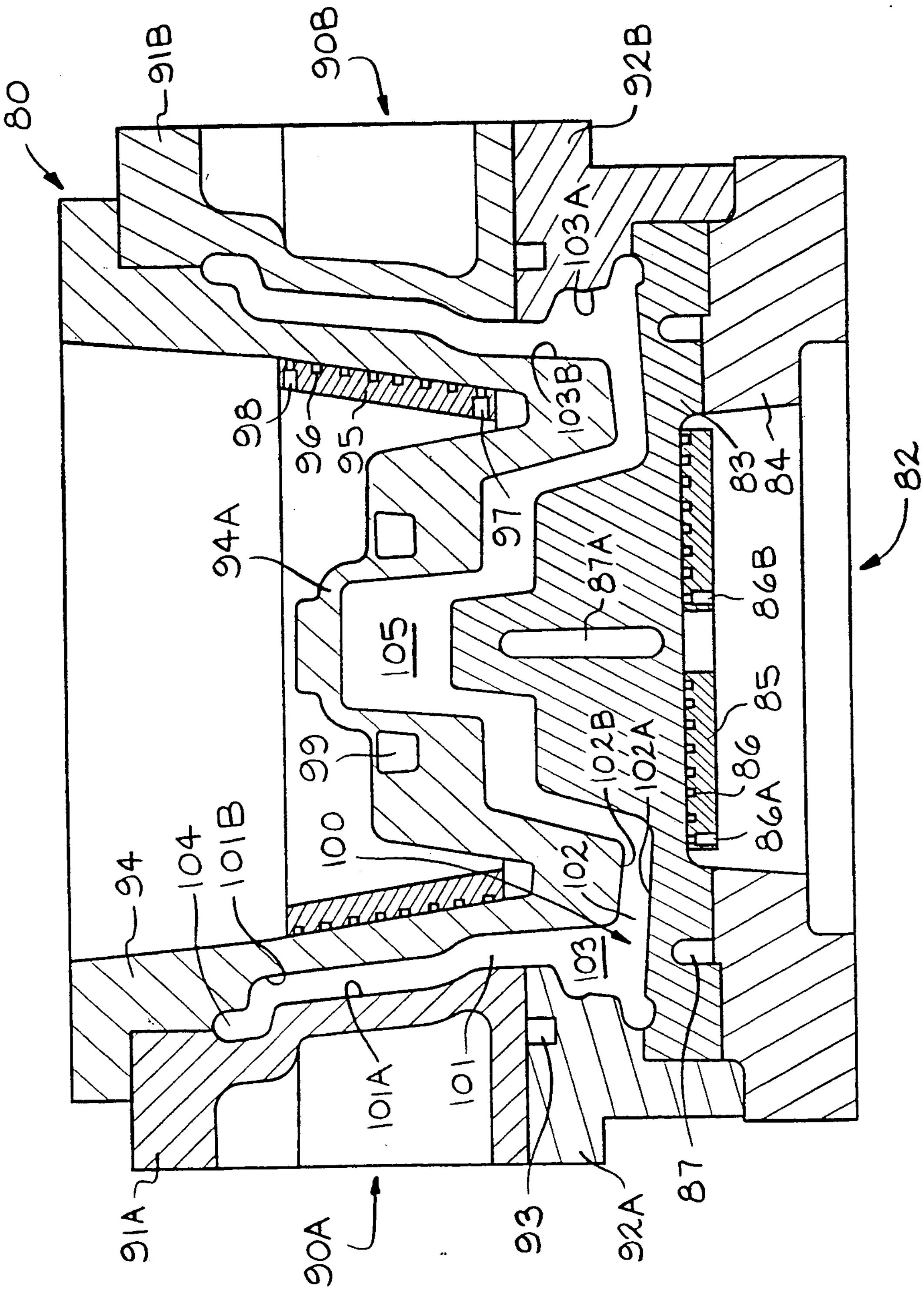
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FIG.6

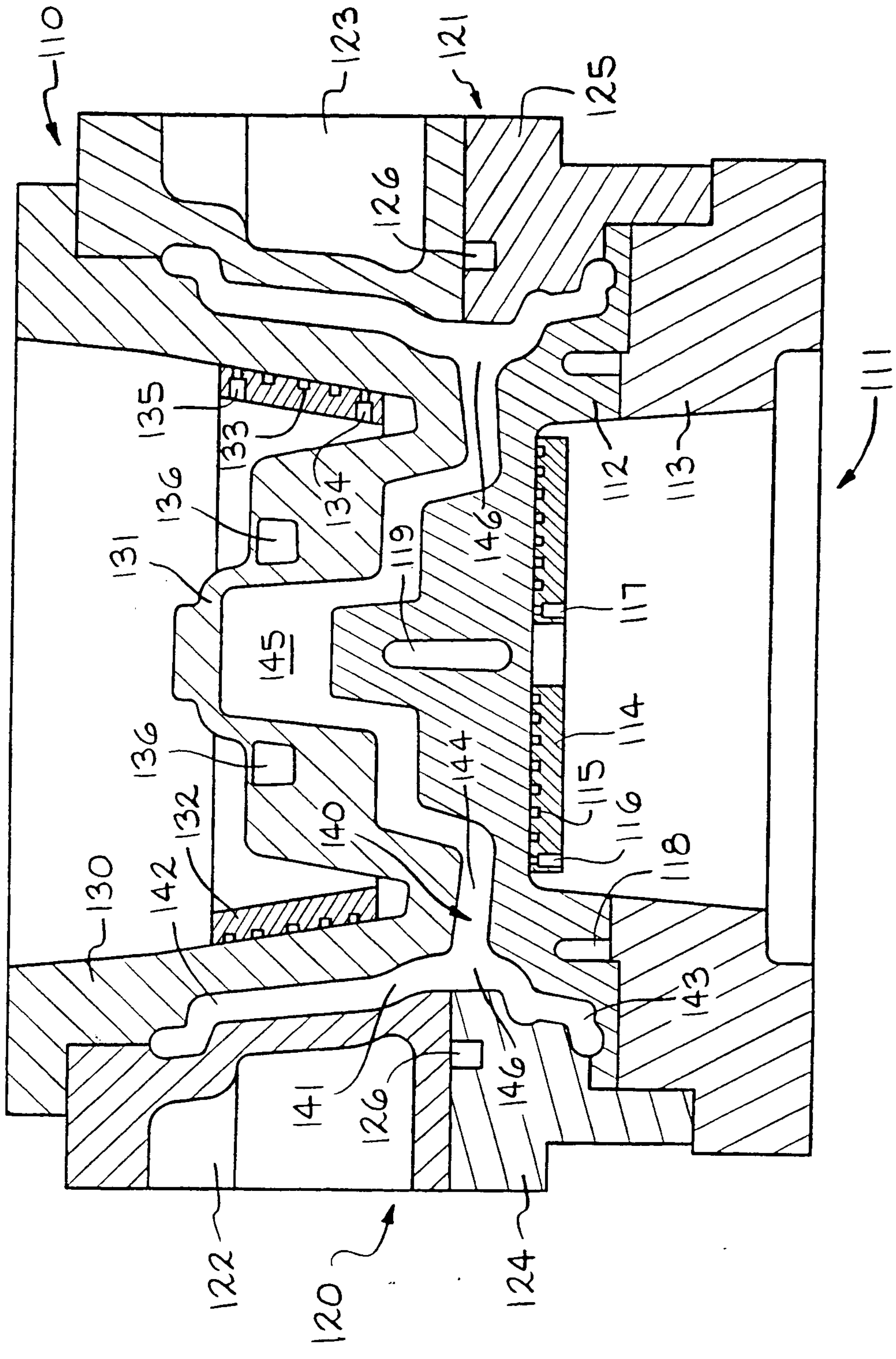
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FIG. 7

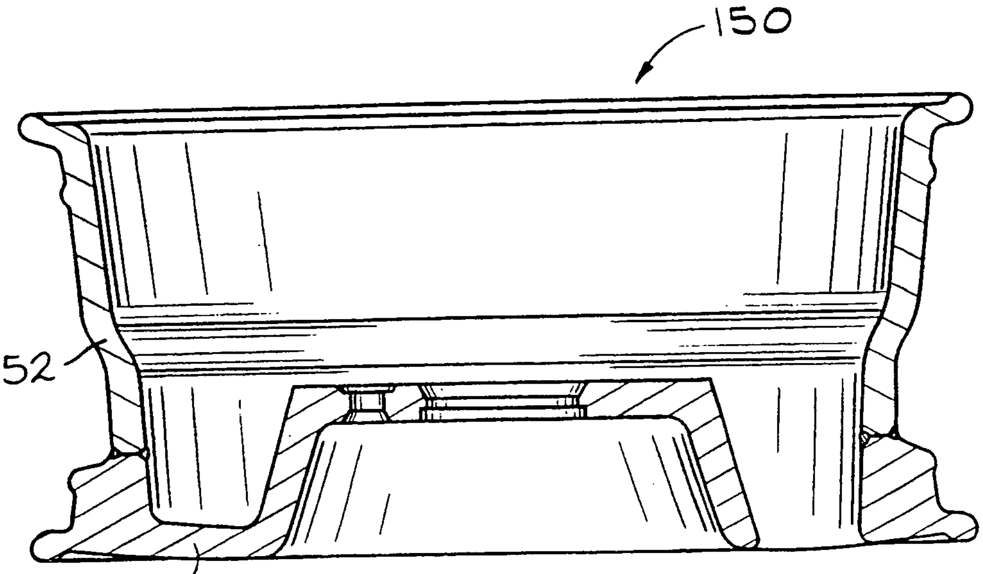
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FIG. 8

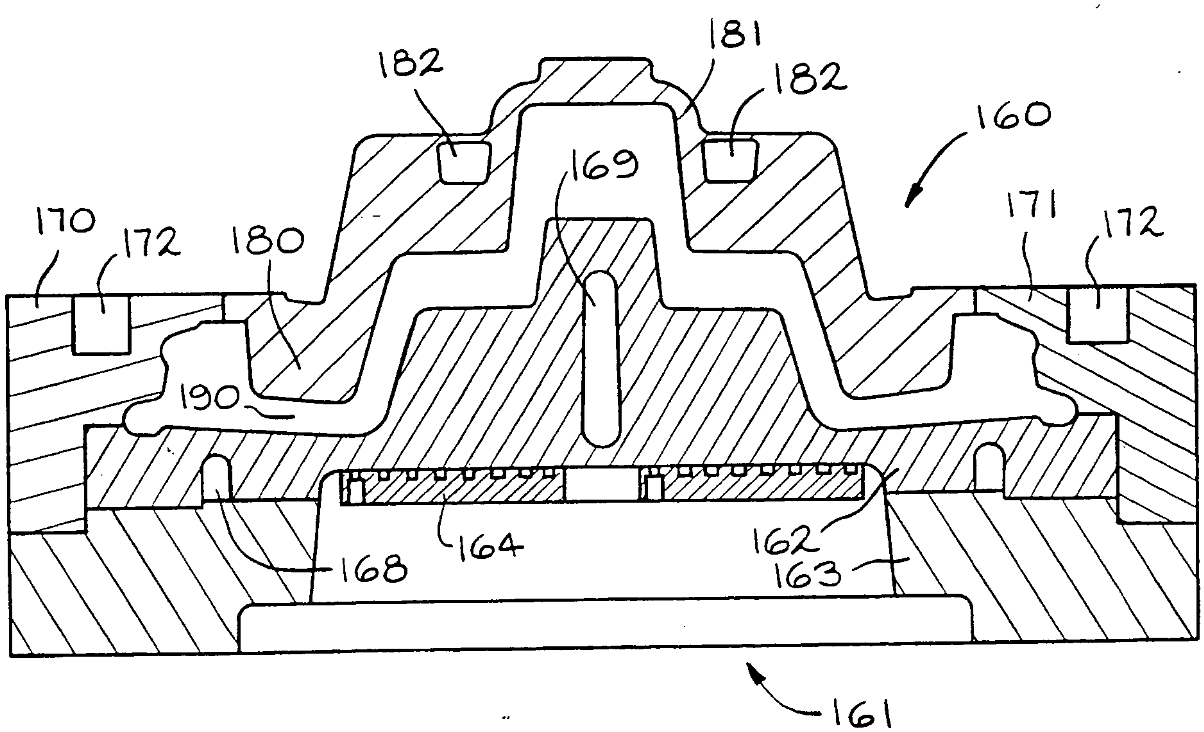
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FIG. 9

INTERNATIONAL SEARCH REPORT

Intern: al Application No
PCT/US 94/11249

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B22D27/04 B22C9/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B22D B22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP,A,0 356 736 (ASAHI KATANTETSU KABUSHIKI KAISHA) 7 March 1990 Table 1 see page 9, line 25 - page 10, line 3; figure 23	1-20
Y	GB,A,2 196 281 (REX HINCHCLIFFE) 27 April 1988 see column 3, line 87 - line 92; figure 1	1-20
A	PATENT ABSTRACTS OF JAPAN vol. 13, no. 565 (M-907) 14 December 1989 & JP,A,01 237 067 (HONDA MOTOR CO LTD) 21 September 1989 see abstract	1,10,16

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
27 January 1995	03.03.95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hodiamont, S

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 17, no. 68 (M-1365) 10 February 1993 & JP,A,04 274 858 (NAKABAYASHI SHIGEMITSU) 30 September 1992 see abstract -----	1,10,16

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 94/11249

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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GB-A-2196281	27-04-88	NONE	